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Effects of Calculator Availability on GRE Quantitative Questions

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ETS, Princeton, NJ

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Educational Testing Service, Princeton, NJ 08541

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Educational Testing Service
Princeton, NJ 08541

Abstract

In order to estimate the likely effects on item difficulty when a calculator becomes available on the quantitative section of the Graduate Record Examinations® (GRE®-Q), 168 items (in six 28-item forms) were administered either with or without access to an on-screen four-function calculator. The forms were administered as a special research section at the end of operational tests, with student volunteers randomly assigned to the calculator or no-calculator groups. Usable data were obtained from 13,159 participants. Test development specialists were asked to rate which items they thought would become easier with a calculator. In general, the specialists were successful in identifying the items with relatively large calculator effects, though even these effects were quite small. An increase of only about four points in the percent correct should suffice for the items identified as likely to show calculator effects with no adjustment needed for the majority of the items. Introduction of a calculator should have little or no effect on gender and ethnic differences.

Key words: Item difficulty, quantitative tests, reasoning skills, computational errors

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Professional standards for assessing quantitative reasoning skills suggest that calculators should be provided to examinees. Because the quantitative portion of the Graduate Record Examinations® General Test (GRE®-Q) emphasizes reasoning skills, and not computational facility, no complex computations are required and a calculator is not needed. Nevertheless, providing a calculator helps to assure that trivial computational errors are not interfering with assessment of the intended reasoning construct. Despite these advantages, introduction of a calculator also introduces some challenges. Specifically, item difficulty estimates for items pretested without a calculator will, in some cases, change when a calculator is introduced. If the effect of the calculator can be estimated for various item types, then the existing item difficulty indices can be appropriately adjusted.

Research with a number of different tests has demonstrated the potential effect of calculators on item difficulty (Ansley, Spratt, & Forsyth, 1989; Hearn & Loyd, 1987; Loyd, 1991; Morgan & Stevens, 1991). A large-scale (7,000 examinees from 275 high schools) study conducted when the calculator was introduced for the SAT®-I indicated a generally positive effect (items became easier) for students who were allowed to use calculators (Bridgeman, Harvey, & Braswell, 1995). Nevertheless, on individual items the calculator could have either no effect on item difficulty, a positive effect, or a negative effect. Items that required nontrivial calculations tended to show positive effects. Only 5 items out of 70 showed negative effects; an example of such an item asked for the remainder when 63,383 is divided by 7. Test developers were reasonably successful in predicting which items would show calculator effects, but they also made some errors. Test developers correctly predicted 20 of the 37 items that showed substantially positive effects; 4 items that were predicted to show negative calculator effects actually showed modest positive effects. In a subsequent unpublished study, I. Lawrence (personal communication, August 2003) developed an adjustment factor so that the difficulty of items of particular types that were pretested without a calculator could be estimated when they were administered with a calculator. This was not a very precise adjustment, but precision was not necessary, since all SAT-I tests are equated after the administration, as will be done for the new GRE linear forms that will replace the GRE CAT in 2006. The adjustment did, nevertheless, help to ensure that the early forms for the test with calculators allowed would meet the appropriate difficulty specifications.

In addition to identifying the adjustment factor for the GRE that should be applied to items that were pretested without a calculator, a second purpose of this research was to evaluate the effects of calculator availability on overall scores. In particular, we sought to determine whether introducing a calculator would have any differential impact on gender and ethnic groups.

Procedure

Test Forms

From the pool of disclosed items that are not widely used in test-preparation materials (e.g., items from forms released in accordance with New York state requirements), we assembled six 28-item linear tests that roughly met the specifications proposed for the new test, for a total of 168 items. We created forms that are consistent with the content changes being recommended for the revised GRE-Q. Specifically, the test forms reflect an increased emphasis on items classified as real, less emphasis on geometry items, and a slightly higher proportion of data-interpretation items. Because our goal was to estimate changes in difficulty for existing types for which difficulty had already been estimated in a no-calculator format, we did not include any of the new format items. These new-format items are being developed and tested in a calculator-available mode.

Test development staff screened the pool of items for those items that become trivial when examinees have access to a calculator. Test development staff also rated each item for calculator sensitivity (negative effect, positive effect, or no effect). (No effect was originally two different points on the scale—"item difficulty unlikely to change" and "item does not lend itself to using the calculator." This distinction was not particularly useful, so these categories were combined for most analyses.) Three staff members independently rated the items, and then a consensus rating was reached after discussion.

Design

Each of the six forms was administered with and without calculator, for a total of 12 groups. Examinees were randomly assigned to one of these groups. For students in the calculator condition, an on-screen calculator could be turned on for any item. The calculator was the four-function plus square root key calculator that is currently used for the Praxis™ computer-based test.

Participants

At the end of the regular GRE tests administered in September and October of 2003, a screen appeared that invited voluntary participation in a research project and offered an incentive not only to participate, but to perform well on this research section. Specifically, potential participants were told that "it is important for our research that you try to do your best on this section," and that they would be eligible to win a $250 prize that would be given "to those 100 test takers who score the highest on questions in the research section relative to how well they did on the preceding scored sections."

A total of 15,811 volunteers participated in the study. From this sample, we dropped 9 who had no valid GRE-Q score on the operational section, and dropped an additional 2,232 who did not appear to be taking the experimental section seriously, as evidenced by failing to complete three fourths of the section. For the remaining students, we performed an equipercentile equating for each of the six forms with the operational quantitative score, and dropped 411 students who were likely not trying because they scored 200 or more points lower on the experimental section than on the operational section. Thus, we were fairly confident that most examinees included in the final sample were making a sincere effort on the experimental section. Losses from this sample screening were comparable across the conditions; 1,323 (17.2%) were dropped from the no-calculator group and 1,329 (16.4%) were dropped from the calculator group. The final sample contained 13,159 participants, or about 1,100 for each of the 12 groups.

Results

Individual results for all 168 items are presented in Appendix A. Items are ordered by the extent of calculator use in the group that had access to a calculator. For the first 20 items listed, at least half of the students who could use a calculator actually did, while for the last 20 items no more than 2% of examinees who could use a calculator chose to use it on these items. In order to summarize these results, we computed the percentage correct for students who took the item with a calculator available and the percentage correct for students who did not have a calculator available, and computed the difference. These difference scores ranged from –5 (i.e., percentage correct was 5 points higher in the no-calculator condition than in the calculator-available condition) to 15. A cross-tabulation of these differences with the test developer ratings of calculator sensitivity is provided in Table 1.

Table 1

Cross-Tabulation of Differences in Percentage Correct, With Test Developer Ratings of Calculator Impact

% correct in calculator-available group minus % correct in no-calculator group	Rating of calculator impact				
	-1	0	1	2	Total
-5	0	2	0	0	2
-4	0	1	1	1	3
-3	0	7	3	3	13
-2	0	4	6	3	**13**
-1	0	6	11	7	**24**
0	0	6	13	5	**24**
1	2	6	8	7	**23**
2	0	4	12	9	**25**
3	1	0	1	5	7
4	1	0	3	7	11
5	0	0	2	6	8
6	0	0	0	4	*4*
7	0	0	0	2	*2*
8	0	0	0	4	*4*
9	0	0	0	1	*1*
10	0	0	0	2	*2*
11	0	0	0	1	*1*
15	0	0	0	1	*1*
Total	4	36	60	68	168

Focusing first on the total column on the far right in Table 1, note that the percentage correct in calculator and no-calculator groups was virtually identical (within two percentage points) for 109 of the 168 items (bold in table). Only 15 items showed differences of more than five percentage points (italics in table). The test developers had identified only four items as likely to show a negative impact of calculator availability, but the actual impact was slightly positive for all of these items. As noted previously, the distinction between a rating of 0 and 1 was not meaningful. Therefore, for subsequent analyses we simplified the rating variable into just two categories, 0 and 1, with 1, 0, and 1 converted to 0, and 2 converted to 1. This simplified variable is used in Figure 1, which shows the scatterplot of percentage correct for items in the no-calculator (x-axis) and calculator-available groups. Items that were identified by the test development experts as likely to show a calculator effect are signified by + on the graph, while the other items are ●. The correlation of item difficulties in the two conditions was very high (r = .98). Items rated as likely to show a calculator effect were generally above the 45-degree line in Figure 1, confirming that these items tend to be somewhat easier when a calculator is available. In addition, effects seem to be greatest for middle-difficulty items. Because most examinees get easy items right without a calculator, the advantage of having a calculator for these items is trivial. Very difficult items are typically conceptually difficult, not computationally difficult, so a calculator is of little benefit on these items also. Even in the middle-difficulty range, most items show little or no calculator effect. Appendix B presents three specific items that illustrate items showing different calculator effects. The first two items are clearly calculation-intensive and show a large effect. The third item also requires calculation, but the calculation is so straightforward that the calculator is of little benefit.

Figure 2 shows the scatterplot of percentage correct in the two calculator conditions by item type. There are two item types: standard multiple-choice questions with five options (5-choice) and quantitative comparison (QC) items in which a quantity in column A must be compared to a quantity in column B, with answer choices indicating whether A is larger, B is larger, they are equal, or there is insufficient information to decide.

QC items are generally designed to be answered quickly, with relatively little calculation needed. Thus, a calculator would generally not be expected to be very useful on this question type, and this seems to be the case, since only 2 of the 78 QC items showed a calculator effect of more than 5 percentage points.

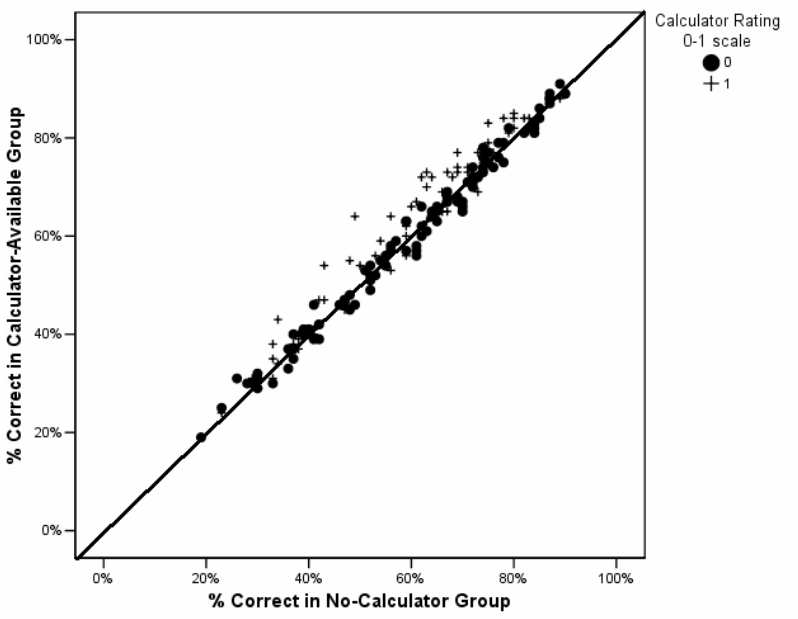

Figure 1. **Scatterplot and regression line showing relationship of item difficulties in the no-calculator and calculator-available groups.**

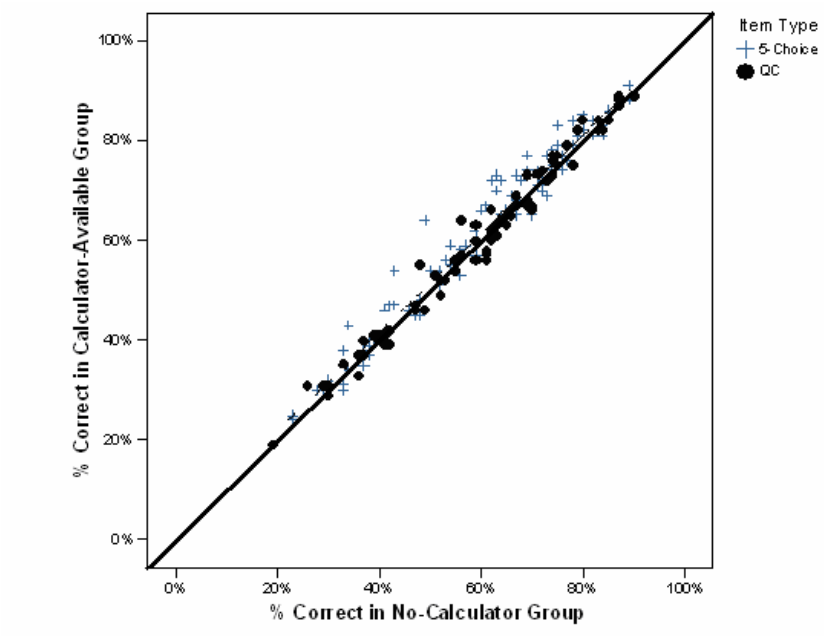

Figure 2. **Scatterplot and regression line showing relationship of item difficulties in the no-calculator and calculator-available groups for two item types.**

Table 2 presents mean differences between percentage correct[1] in the no-calculator and calculator-available groups across calculator conditions for a crossing of test developer calculator ratings, item type, and pure versus real item classification. In general, real problems are word problems with applied contexts, while pure problems are numbers presented with a minimum of words. The first row in this table indicates that for the 24 pure, five-choice questions that were rated as likely to have no calculator impact, the mean difference between the percentage correct in the calculator and no-calculator conditions was 0.21. Across item types, items rated as not likely to show calculator effects did, indeed, show minimal mean differences. Items rated as likely to show some calculator effects typically showed average differences of about 3 or 4 percentage points between the calculator and no-calculator conditions. The eight real QC items were an exception, showing an average difference of only 0.25 percentage points even when rated as likely to show calculator effects.

Table 2

Mean Differences in Item Difficulty (Percentage Correct) for Items of Different Types and Rated Sensitivity

Calc. rating	Type		Mean	*N*	SD
0	5C	Pure	.21	24	2.06
		Real	-.06	16	1.95
		Total	.10	40	2.00
	QC	Pure	-.33	48	2.14
		Real	.58	12	2.35
		Total	-.15	60	2.19
1	5C	Pure	4.29	7	4.42
		Real	3.26	43	3.95
		Total	3.40	50	3.98
	QC	Pure	2.50	10	2.06
		Real	.25	8	2.19
		Total	1.50	18	2.87

Note. N is the number of items. Each item was answered by at least 1,000 people in the calculator-available group and 1,000 in the no-calculator group.

Effects on Total Score

Given that only 15 out of the 168 items showed calculator effects of more than five percentage points, the effect on total scores would be expected to be rather modest. Table 3 contrasts the total scores (on the 200–800 GRE scale) of examinees in the no-calculator and calculator-available conditions.

Table 3

Mean Score on Experimental Section for No-Calculator and Calculator-Available Groups

	Mean		SD		Sample size	
Ethnic group/gender	No-calculator	Calculator available	No-calculator	Calculator available	No-calculator	Calculator available
White/male	648	656	121	120	1,214	1,348
White/female	571	582	126	128	2,226	2,451
Asian American/ male	692	707	106	97	218	213
Asian American/ female	642	641	123	116	233	265
African American/male	524	541	153	143	104	91
African American/female	453	460	130	125	266	244
Hispanic/male	590	612	135	131	107	91
Hispanic/female	518	517	131	117	158	181
Other/male	637	654	123	116	174	183
Other/female	570	582	137	134	157	162
Total/male	642	654	128	123	1,817	1,926
Total/female	563	574	133	132	3,040	3,303

As shown in Table 4, an analysis of variance, with the operational quantitative score, calculator availability, gender, and ethnic group (African American, Asian American, Hispanic, White, and Other) as independent variables, indicated a small but statistically significant main

effect for calculator use, but no significant interactions. This analysis treated each of the six equated test forms as equivalent in order to create a single dependent variable. Repeating the analysis separately for each test form also indicated no significant interactions. This suggests that introduction of a calculator should not be expected to have much impact on gender or ethnic differences.

Table 4

Analysis of Variance for Combined Test Forms

Source	Type III sum of squares	Df	Mean square	F	Sig.
Gender (G)	437.642	1	437.642	.073	.787
Ethnic group (E)	37,283.443	4	9,320.861	1.557	.183
Calculator availability (A)	3,3479.804	1	33,479.804	5.591	.018
GRE quantitative score (Q)	38,438,106.590	1	38,438,106.59	6,419.473	.000
G X E	29,169.979	4	7,292.495	1.218	.301
G X A	758.230	1	758.230	.127	.722
G X Q	14,213.684	1	14,213.684	2.374	.123
E X A	21,590.202	4	5,397.551	.901	.462
E X Q	41,722.743	4	10,430.686	1.742	.138
A X Q	11,763.833	1	11,763.833	1.965	.161
G X E X A	33,801.558	4	8,450.389	1.411	.227
G X E X Q	35,202.048	4	8,800.512	1.470	.208
G X A X Q	1,776.463	1	1,776.463	.297	.586
E X A X Q	17,693.180	4	4,423.295	.739	.565
G X E X A X Q	36,496.132	4	9,124.033	1.524	.192
Error	6,015,2794.346	10,046	5,987.736		
Total	3,796,018,700.000	10,086			
Corrected total	185,920,647.600	10,085			

Difficulty Differences by Calculator Use

The above analyses contrast the item difficulties for the groups of students who did or did not have access to a calculator during the test. This is the question of primary interest for estimating the likely effects on item difficulty of introducing a calculator. A secondary question is a comparison of difficulty differences for students who not only had access to a calculator but who actually used it for a given question compared to students who had access but chose to answer the question without using the calculator. (*Used* is our shorthand for indicating that the examinee switched on the calculator for a particular item; it is possible that for some items the calculator was turned on, but that the examinee did not actually do any calculations with it.) At the individual item level, calculator use was relatively rare. For 86 of the 168 items, fewer than 20% of the examinees who could use the calculator actually did use the calculator. For only 20 items was the calculator used by more than half of the examinees, and the item with the most calculator use still had only 61% of the examinees who could use a calculator actually choosing to use a calculator on that item. Nevertheless, differences in percentage correct were sometimes quite substantial between students who chose to use or not use the available calculator. The largest apparent benefit of the calculator was noted for an item on which 36% of the examinees chose to use a calculator, and the percentage correct for these examinees was 71%, compared to 27% for the examinees who chose not to use the calculator. These results must be interpreted cautiously because the students choosing to use a calculator also had higher quantitative ability as indexed by their average scores from the operational section of the test (657, vs. 567 for students who chose not to use a calculator). However, there were a few items in which the mean operational scores were higher in the group choosing not to use a calculator, but there was still an apparent advantage to calculator use. For an item on which 53% of examinees chose to use a calculator, the mean quantitative score was 611 in the not-used group and 593 in the used group, but the percentage correct was 66% in the not-used group and 84% in the used group.

Differences in percentage correct for students choosing to use or not use an available calculator are presented in Figure 3. In order to avoid over-interpretation of differences based on very small samples (i.e., for items on which very few people chose to use a calculator), Figure 3 includes only the 20 items for which at least 50% of the students with an available calculator chose to use it. Recall that, for these items, at least 39% of the examinees chose not to use a calculator. Points above the 45-degree diagonal indicate higher scores in the group that chose to

use a calculator. For half of these items, the difference in percentage correct was over 20 percentage points. Although this result is intriguing, it would not be correct to label it as a true calculator effect because of the self-selection in choosing to use a calculator. For items that appear to be calculator-sensitive, better students may chose to use a calculator even though they might have done just as well without a calculator.

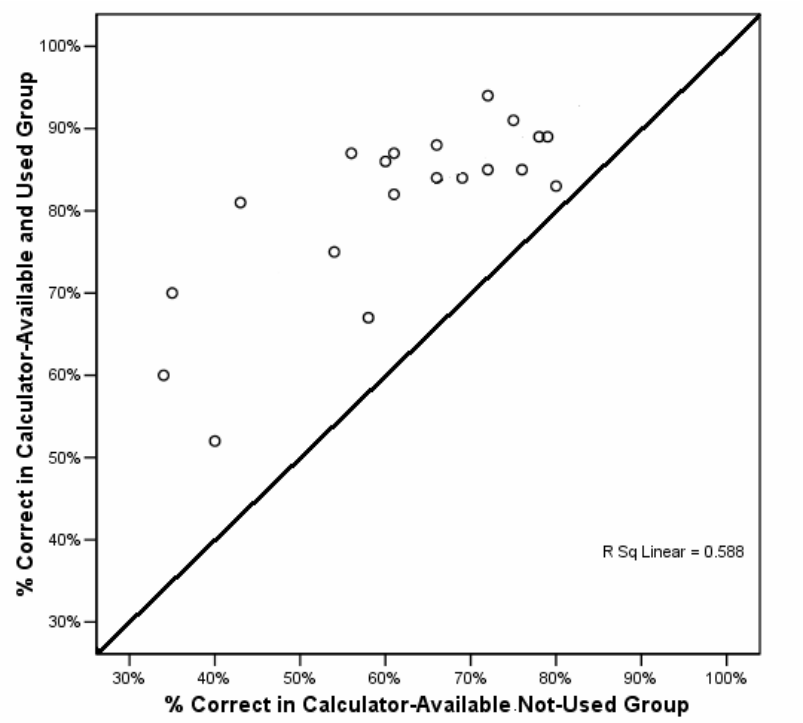

Figure 3. **Scatterplot, regression line (light), and 45-degree line (bold) showing relationship of item difficulties in the calculator-available-but-not-used group and the calculator-available-and-used group.**

Calculator Effects on Item Times

For each item, the mean time to complete the item was computed separately for the no-calculator and calculator-available groups. These times are summarized in Figure 4.

Points below the 45-degree line indicate items that were answered more quickly in the calculator-available group. In general, times appear to be faster for examinees who had access to a calculator, especially on the items that were rated as calculator sensitive by the test development experts.

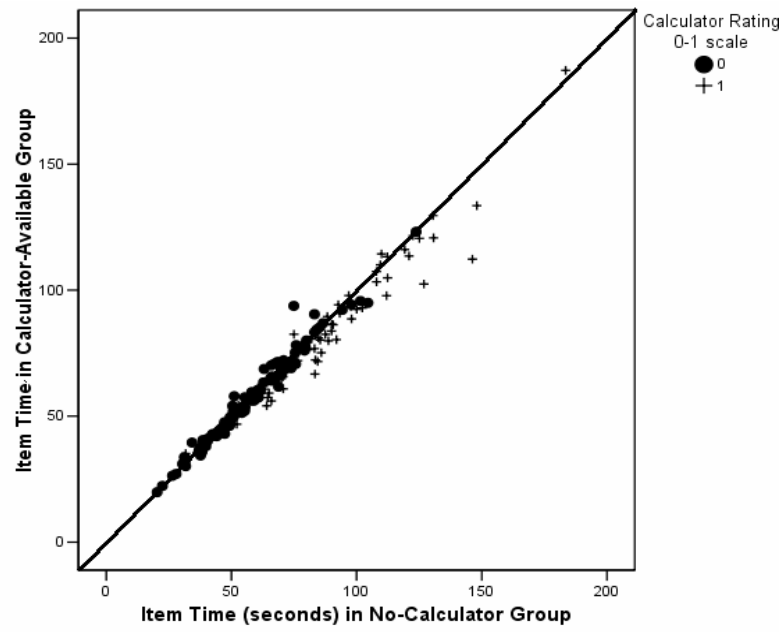

Figure 4. **Scatterplot, regression line (light), and 45-degree line (bold) showing relationship of item time (in seconds) in the no-calculator and calculator-available groups.**

The time advantage for the 20 items with heaviest calculator use is shown in Figure 5. The points are predominantly below the 45-degree line, indicating a time advantage to calculator use on the most calculator-active items.

Conclusions

For most of the GRE-Q items studied, the effect of having access to a calculator was relatively small. Although there were a few exceptions, test developers were generally quite accurate in identifying which items were likely to show substantial calculator effects. For items identified by test developers as likely to show effects, adding about four percentage points to the existing difficulty estimate should suffice. An exception to this rule could be made for real QC items, which do not appear to need an adjustment even when identified by test developers as likely to show a calculator effect. Because test forms will be equated after they are administered, the difficulty estimates do not have to be nearly as precise as they would for the pre-calibrated items used in the current computer-adaptive test. These results suggest that the adjusted estimates should be good enough for a test with post-administration equating. The few items that show substantial calculator effects should not interfere with the ability of the test as a whole to provide comparable reported scores.

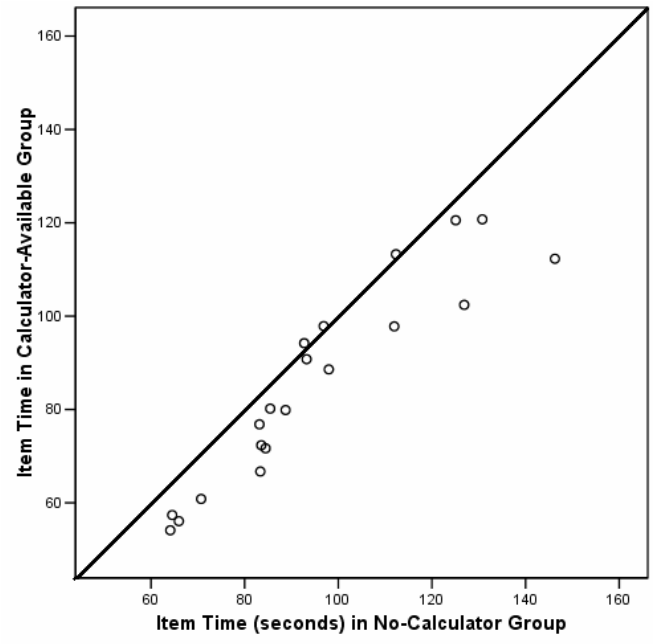

Figure 5. **Scatterplot and 45-degree line showing relationship of item time in the no-calculator and calculator-available groups for the 20 items with the heaviest calculator use.**

Note. Includes only the 20 items for which at least 50% of examinees chose to use a calculator.

The substantial effects noted for examinees who choose to use a calculator, compared to those who choose not to use it when available, are open to different interpretations and do not necessarily reflect a true calculator effect. Nevertheless, they suggest that continued monitoring is desirable as test takers become more familiar with ways to use the calculator most effectively.

Any time differences related to calculator use should not be of great concern. The time limits for the new GRE are being set in field trials that include access to a calculator, so these time differences are already being taken into account.

Calculator benefits appeared to be relatively constant across gender and ethnic groups, with no significant interactions of gender or ethnicity with calculator availability. As coaching schools and tutors begin to prepare students for a calculator-available GRE, this situation could change. The best way to prevent any disparate impact from the introduction of calculators is to make sure that materials that demonstrate the most effective ways to use a calculator on the GRE are available to all students.

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Notes

[1] Computing means on differences in percentage correct can be problematic because differences at the extremes (e. g., 90% to 95% correct) probably reflect greater differences in intrinsic difficulty than differences near the middle (e.g., 40% to 45% correct). To adjust for this, a nonlinear transformation of percent correct to *z*-scores or delta scores sometimes is used. However, this transformation makes a noticeable difference only for extreme values (Donlon & Livingston, 1984). Over the range of difficulties in the current study, the transformation is virtually linear, so we used the simpler percent correct metric.

Appendix A

Item Classification, Percentage Correct, and Item Time for Examinees With and Without Calculator Availability, and Calculator Usage for Each Item

Item number	Accession number	Item classification				Developer rating	No calculator		Calculator available		
		Type	1	2	Subject		% correct	Time	% correct	Time	% used
1	DQ001343	QC	Arithmetic	Pure	Measurement conversion	2	56%	71	64%	61	61%
2	VB362260	5C	Arithmetic	Real	Interest, sales tax, etc.	2	80%	131	85%	121	61%
3	DQ002624	5C	Data	Real	Percent (basic)	2	78%	84	84%	72	60%
4	VB368883	5C	Geometry	Real	Quadrilateral area	2	60%	146	66%	112	59%
5	DQ002625	5C	Data	Real	Percentage change	2	49%	98	64%	89	57%
6	LB006142	5C	Data	Pure	Mean (arithmetic mean)	2	79%	97	81%	98	57%
7	WV000485	5C	Arithmetic	Real	Ratio, proportion	2	80%	64	82%	54	57%
8	DM100263	5C	Data	Real	Weighted mean	2	75%	85	79%	80	56%
9	LB001461	5C	Data	Real	Percentage change	2	43%	93	54%	94	55%
10	LB007148	5C	Arithmetic	Real	Rate (e.g., MPG, dollars/hour)	2	82%	65	84%	57	55%
11	DQ003334	5C	Data	Real	Computation—decimals	2	41%	125	46%	121	54%
12	VB356082	5C	Data	Real	Sets	2	75%	112	75%	113	53%
13	DQ002533	5C	Data	Real	Rate	2	68%	127	72%	102	53%
14	LB007115	QC	Data	Real	Computation-fractions	2	80%	93	84%	91	53%

(Table continues)

Table (continued)

Item number	Accession number	Item classification				Developer rating	No calculator		Calculator available		
		Type	1	2	Subject		% correct	Time	% correct	Time	% used
15	DQ003332	5C	Data	Real	Computation-fractions	2	64%	112	72%	98	52%
16	LB001489	5C	Data	Real	Computation—decimals	2	69%	83	74%	67	52%
17	LB008809	5C	Data	Real	Counting (combinatorics)	2	42%	83	47%	77	51%
18	WW001574	5C	Data	Real	Probability	2	73%	89	77%	80	51%
19	LB001671	5C	Arithmetic	Pure	Factors, multiples, divisibility	2	63%	84	73%	72	50%
20	WW001575	5C	Data	Real	Mean (arithmetic mean)	2	69%	66	77%	56	50%
21	M-072094	5C	Arithmetic	Real	Ratio, proportion	2	75%	102	83%	93	50%
22	VB179876	5C	Algebra	Real	Linear equation	2	77%	90	79%	87	46%
23	VB102042	5C	Geometry	Pure	Combination	2	37%	90	38%	84	46%
24	DQ007280	5C	Data	Real	Percent (basic)	2	74%	65	75%	59	46%
25	DR000032	5C	Data	Real	Percent (basic)	2	67%	119	65%	116	45%
26	VB371114	5C	Arithmetic	Real	Profit and loss	2	61%	148	67%	134	45%
27	AY002038	5C	Data	Pure	Mean (arithmetic mean)	1	64%	105	65%	95	45%
28	DQ003246	5C	Algebra	Pure	Linear equation	2	67%	112	73%	105	44%
29	LB022229	5C	Data	Real	Estimation	2	43%	184	47%	187	44%

(Table continues)

Table (continued)

Item number	Accession number	Item classification				Developer rating	No calculator		Calculator available		
		Type	1	2	Subject		% correct	Time	% correct	Time	% used
30	LB001956	QC	Data	Pure	Mean (arithmetic mean)	2	74%	52	77%	47	43%
31	DM001716	5C	Data	Real	Percent change	2	33%	70	31%	65	43%
32	DQ003794	5C	Data	Real	Percent (basic)	2	73%	98	69%	93	42%
33	LB010341	5C	Data	Real	Probability	2	66%	121	69%	114	42%
34	DW001378	5C	Arithmetic	Real	Ratio, proportion	2	71%	108	74%	103	41%
35	WW001961	QC	Data	Real	Weighted mean	1	51%	70	53%	67	41%
36	DQ002656	5C	Algebra	Pure	Linear equation	1	84%	69	83%	62	41%
37	LB002851	5C	Geometry	Real	Pythagorean theorem	2	63%	86	70%	75	40%
38	DM001718	5C	Data	Real	Percent (basic)	2	33%	92	38%	80	40%
39	DC005107	5C	Data	Real	Mean (arithmetic mean)	2	84%	49	83%	48	39%
40	VB376016	5C	Algebra	Pure	Quadratic/other/inequality	1	65%	76	66%	78	39%
41	DQ001367	5C	Data	Real	Probability	1	67%	47	67%	46	39%
42	DQ002536	5C	Data	Real	Ratio, proportion	2	54%	110	59%	110	39%
43	VB175951	5C	Algebra	Pure	Applying formula	2	89%	53	88%	54	38%
44	DQ003796	5C	Data	Real	Angles in the plane	2	59%	71	62%	66	38%

(Table continues)

Table (continued)

Item number	Accession number	Item classification				Developer rating	No calculator		Calculator available		
		Type	1	2	Subject		% correct	Time	% correct	Time	% used
45	DM002194	5C	Data	Real	Measurement conversion	1	73%	79	72%	76	37%
46	DR000328	5C	Geometry	Real	Quadrilateral perimeter	1	74%	75	78%	72	37%
47	LB010440	5C	Data	Real	Mean (arithmetic mean)	2	57%	123	59%	122	37%
48	LB001459	5C	Data	Real	How many categories	2	34%	77	43%	77	36%
49	DW002095	5C	Data	Real	Percent of Percent6	2	23%	131	24%	130	36%
50	LB022113	QC	Algebra	Real	Profit and loss	-1	37%	70	40%	69	35%
51	PV000319	QC	Arithmetic	Real	Percent (basic)	2	83%	81	84%	76	35%
52	DM001305	5C	Data	Pure	Probability	1	41%	71	46%	71	35%
53	VB366166	5C	Arithmetic	Pure	Negative exponents	2	62%	48	72%	47	34%
54	M-069053	QC	Algebra	Pure	Linear equation	1	79%	40	82%	41	33%
55	DQ001368	5C	Data	Real	Median	0	59%	66	57%	65	33%
56	DR000035	5C	Data	Real	Mean (arithmetic mean)	1	52%	75	54%	94	33%
57	DC000493	5C	Data	Real	Percent (basic)	2	84%	62	81%	63	33%
58	VB380644	QC	Arithmetic	Pure	Exponents	1	19%	61	19%	60	32%
59	DM002418	QC	Algebra	Pure	Newly defined functions	2	66%	75	66%	83	30%

(Table continues)

Table (continued)

Item number	Accession number	Item classification				Developer rating	No calculator		Calculator available		
		Type	1	2	Subject		% correct	Time	% correct	Time	% used
60	IF000478	5C	Data	Real	Percent change	2	50%	85	54%	81	30%
61	DM001370	5C	Data	Real	Percent change	2	47%	87	45%	82	30%
62	DM001394	QC	Data	Real	Mean/median Comparison	1	39%	72	41%	69	29%
63	WW002249	QC	Arithmetic	Pure	Exponents	-1	56%	31	57%	34	29%
64	LB006128	QC	Arithmetic	Real	Ratio, proportion	2	59%	76	60%	72	28%
65	DW002092	5C	Data	Real	How many categories	2	76%	73	77%	71	28%
66	WW002073	5C	Arithmetic	Real	Rate (e.g., MPG, dollars/hour)	1	74%	84	74%	84	28%
67	DC000083	QC	Algebra	Pure	Linear inequality	2	63%	58	63%	57	27%
68	M-035486	5C	Data	Real	Ratio, proportion	2	38%	108	37%	107	27%
69	DW000520	QC	Arithmetic	Real	Measurement conversion	2	71%	58	73%	56	26%
70	DM001369	5C	Data	Real	Ratio, proportion	1	76%	71	74%	72	26%
71	AY000912	QC	Algebra	Pure	Linear inequality	2	48%	64	55%	63	26%
72	DM100219	5C	Algebra	Real	Ratio, proportion	1	75%	74	77%	69	25%
73	DM002196	5C	Data	Real	Miscellaneous	2	38%	100	39%	92	24%
74	BE000402	QC	Algebra	Pure	Positive and negative numbers	0	70%	34	67%	40	24%

(Table continues)

Table (continued)

Item number	Accession number	Item classification				Developer rating	No calculator		Calculator available		
		Type	1	2	Subject		% correct	Time	% correct	Time	% used
75	DQ003175	5C	Arithmetic	Real	Graduated rate	1	72%	80	70%	77	24%
76	DM001891	QC	Data	Real	Counting (combinatorics)	1	40%	80	41%	80	22%
77	VB110055	5C	Algebra	Pure	Series and sequences	0	30%	79	32%	78	21%
78	WW002063	QC	Geometry	Pure	Triangle area	1	69%	51	67%	58	21%
79	DM002300	5C	Data	Pure	Median	1	78%	50	79%	54	21%
80	LB010349	5C	Data	Real	Read data	2	56%	88	53%	90	20%
81	DM001717	5C	Data	Real	Ratio, proportion	2	53%	110	56%	114	20%
82	VB340313	QC	Data	Real	Weighted mean	1	62%	67	66%	71	19%
83	UB100012	QC	Geometry	Pure	Combination	2	41%	91	41%	86	19%
84	LB010436	5C	Data	Real	Computation—fractions	1	90%	61	89%	60	19%
85	DM001645	QC	Arithmetic	Pure	Negative exponents	1	62%	40	60%	38	19%
86	VB383223	QC	Algebra	Real	Percent of percent	2	41%	82	40%	81	18%
87	DM001714	5C	Data	Real	Computation—integers	1	56%	124	58%	123	18%
88	LB002848	QC	Geometry	Pure	Pythagorean theorem	2	33%	49	35%	49	18%
89	VB363670	QC	Data	Pure	Median	0	62%	52	62%	53	16%

(Table continues)

Table (continued)

Item number	Accession number	Item classification				Developer rating	No calculator		Calculator available		
		Type	1	2	Subject		% correct	Time	% correct	Time	% used
90	UB100001	QC	Data	Real	Percent change	2	59%	63	56%	61	16%
91	VB355893	QC	Geometry	Pure	Combination:	2	73%	36	72%	36	16%
92	VB106018	5C	Arithmetic	Real	Series and sequences	1	46%	98	46%	94	16%
93	AY002228	QC	Algebra	Pure	Systems of equations/inequalities	1	42%	102	39%	96	16%
94	DM001169	5C	Geometry	Pure	Combination	1	23%	94	25%	92	16%
95	PV000271	QC	Algebra	Pure	Algebraic manipulation	1	55%	55	54%	57	16%
96	DM001623	QC	Geometry	Real	Circle area	2	66%	60	65%	58	16%
97	SE002197	QC	Arithmetic	Real	Percent change	2	66%	40	65%	41	15%
98	M-077877	QC	Algebra	Pure	Computation—radicals	-1	40%	39	41%	41	14%
99	LB001446	QC	Arithmetic	Pure	Properties of operations	1	55%	42	56%	42	14%
100	DM001642	5C	Algebra	Pure	Systems of equations/inequalities	1	71%	83	71%	83	13%
101	VB348669	5C	Data	Pure	Counting (combinatorics)	0	29%	63	30%	69	13%
102	VB366165	5C	Arithmetic	Pure	Negative exponents	1	57%	45	59%	44	12%
103	SE002196	QC	Geometry	Pure	Combination	1	67%	55	67%	54	12%
104	VB328701	QC	Geometry	Pure	Quadrilateral area	1	75%	46	75%	45	12%

(Table continues)

Table (continued)

Item number	Accession number	Item classification				Developer rating	No-calculator		Calculator-available		
		Type	1	2	Subject		% correct	Time	% correct	Time	% used
105	LB010364	QC	Arithmetic	Pure	Properties of operations	2	69%	32	73%	35	11%
106	DQ000381	QC	Geometry	Pure	Quadrilateral area	1	55%	49	54%	49	11%
107	LB010276	QC	Algebra	Pure	Newly defined functions	1	83%	37	82%	37	11%
108	AY001323	QC	Algebra	Pure	Algebraic manipulation	0	72%	58	74%	60	11%
109	WW002167	QC	Arithmetic	Real	Computation—integers	1	87%	46	87%	45	11%
110	VB384970	5C	Arithmetic	Pure	Series and sequences	2	38%	79	40%	78	11%
111	DM100273	QC	Algebra	Real	Rate (e.g., MPG, dollars/hour)	1	61%	66	57%	70	10%
112	LB007923	5C	Arithmetic	Real	Rate (e.g., MPG, dollars/hour)	1	89%	47	91%	43	10%
113	VB382618	QC	Arithmetic	Pure	Remainders	0	36%	53	37%	52	9%
114	VB352058	QC	Arithmetic	Real	Graduated rate	1	87%	43	88%	43	9%
115	VB179819	QC	Algebra	Pure	Computation—fractions	0	61%	66	56%	66	9%
116	WV000243	5C	Data	Pure	Sets	1	82%	55	81%	52	8%
117	DQ001593	QC	Data	Pure	Mean/median comparison	1	64%	42	64%	42	8%
118	VB368885	5C	Data	Pure	Probability	1	28%	87	30%	87	7%
119	DC030101	QC	Geometry	Pure	Combination:	1	65%	49	65%	47	7%

(Table continues)

Table (continued)

Item number	Accession number	Item classification				Developer rating	No calculator		Calculator available		
		Type	1	2	Subject		% correct	Time	% correct	Time	% used
120	LB010346	5C	Data	Real	Which category/categories	2	34%	51	34%	51	7%
121	VB155808	QC	Arithmetic	Pure	Series and sequences	0	41%	83	39%	90	7%
122	AY001121	QC	Geometry	Pure	Angles in the plane	0	70%	54	66%	53	7%
123	DM002163	QC	Geometry	Pure	Coordinate geometry	0	47%	40	46%	40	7%
124	VB376019	QC	Algebra	Pure	Quadratic/other equation/inequality	0	52%	67	52%	65	6%
125	DW001388	5C	Data	Real	Percent (basic)	1	52%	76	51%	71	6%
126	WV000104	QC	Geometry	Pure	Triangle area	0	84%	32	82%	33	6%
127	DC000518	5C	Geometry	Pure	Triangle area	1	72%	51	72%	50	6%
128	DM001844	QC	Data	Pure	Probability	1	59%	38	63%	34	6%
129	DM001363	QC	Algebra	Pure	Coordinate geometry	2	29%	54	31%	55	6%
130	DC000276	QC	Arithmetic	Pure	Computation—fractions	0	61%	38	58%	36	6%
131	DQ007318	QC	Arithmetic	Real	Rate (e.g., MPG, dollars/hour)	0	75%	53	77%	52	6%
132	VB352654	QC	Geometry	Pure	Triangle perimeter/triangle inequality	1	30%	68	29%	72	6%
133	VB315299	QC	Algebra	Pure	Algebraic manipulation	-1	59%	60	63%	58	6%
134	VB352042	QC	Data	Real	Sets	1	37%	47	37%	43	5%

(Table continues)

Table (continued)

Item number	Accession number	Item classification				Developer rating	No calculator		Calculator available		
		Type	1	2	Subject		% correct	Time	% correct	Time	% used
135	DR000516	QC	Geometry	Pure	Coordinate geometry	1	67%	51	69%	52	5%
136	JM001367	QC	Algebra	Pure	Systems of equations/inequalities	0	90%	31	89%	31	5%
137	DC000487	5C	Data	Real	Order	1	77%	72	76%	70	5%
138	WW001069	QC	Algebra	Pure	Properties of operations	0	77%	31	79%	31	5%
139	WW001426	QC	Algebra	Pure	Computation—integers	1	87%	26	88%	26	5%
140	LB009196	5C	Algebra	Pure	Absolute value	0	48%	72	45%	70	4%
141	VB333458	QC	Algebra	Pure	Slope	1	78%	75	75%	75	4%
142	VB143721	QC	Arithmetic	Pure	Positive and negative numbers	1	87%	32	89%	33	3%
143	VB384454	QC	Algebra	Pure	Negative exponents	0	36%	43	33%	43	3%
144	DT000175	QC	Algebra	Pure	Algebraic manipulation	0	40%	58	40%	56	3%
145	VB378850	5C	Arithmetic	Pure	Factors, multiples, divisibility	0	70%	67	65%	65	3%
146	LB002943	QC	Geometry	Pure	Lines and segments	1	63%	54	61%	51	3%
147	DQ001806	5C	Data	Pure	Counting (combinatorics)	0	84%	50	81%	48	2%
148	LB008785	5C	Algebra	Pure	Absolute value	0	54%	44	55%	42	2%
149	DM001790	QC	Data	Pure	Probability	0	30%	22	31%	22	2%

(Table continues)

Table (continued)

Item number	Accession number	Item classification				Developer rating	No calculator		Calculator available		
		Type	1	2	Subject		% correct	Time	% correct	Time	% used
150	DC000153	5C	Algebra	Pure	Algebraic manipulation	0	67%	61	61%	57	2%
151	DM001220	5C	Algebra	Pure	Positive and negative numbers	0	72%	44	71%	43	2%
152	M-075074	QC	Arithmetic	Real	Ratio, proportion	0	53%	58	52%	56	2%
153	NT000450	QC	Algebra	Pure	Quadratic/other equation/inequality	0	49%	59	46%	56	2%
154	DQ001633	QC	Arithmetic	Pure	Primes, prime factorization	1	74%	38	76%	38	2%
155	AY002477	QC	Geometry	Pure	Angles in the plane	0	69%	47	68%	48	2%
156	WW002335	5C	Geometry	Pure	Combination: circle/quad/area/peri	1	85%	38	86%	37	2%
157	UB100529	QC	Algebra	Pure	Newly defined functions	1	47%	49	47%	46	2%
158	WW002340	QC	Arithmetic	Pure	Factors, multiples, divisibility	1	65%	28	63%	27	1%
159	DQ002900	QC	Algebra	Pure	Order	1	74%	32	73%	30	1%
160	LB002905	5C	Arithmetic	Pure	Exponents	0	37%	55	35%	54	1%
161	LB001664	QC	Geometry	Real	Quadrilateral area	0	52%	60	49%	58	1%
162	VB358467	5C	Geometry	Pure	Coordinate geometry	0	48%	85	48%	85	1%
163	VB324359	QC	Algebra	Pure	Positive and negative numbers	1	26%	32	31%	32	1%
164	DM001942	5C	Data	Pure	Standard deviation	0	39%	31	40%	31	1%

(Table continues)

Table (continued)

Item number	Accession number	Item classification				Developer rating	No calculator		Calculator available		
		Type	1	2	Subject		% correct	Time	% orrect	Time	% used
165	LB022237	5C	Data	Real	Read data	1	33%	66	30%	64	1%
166	AY002342	QC	Geometry	Pure	Triangle perimeter/triangle inequality	0	42%	37	42%	36	1%
167	DM001628	5C	Geometry	Pure	X, Y intercepts		47%	63	47%	63	0%
168	DC005082	QC	Geometry	Pure	Combination	0	85%	20	84%	20	0%

Appendix B

Item Examples

Item 48

These questions refer to the following table.

Population Profile of the United States, Census Years 1900 – 1990

Year	Population	Percent increase	Population per square mile	Percent urban/rural	Median age (in years)
1900	75,994,575	20.7	25.6	39.6/60.4	22.9
1910	91,972,266	21.0	31.0	45.6/54.4	24.1
1920	105,710,620	14.9	35.6	51.2/48.8	25.3
1930	122,775,046	16.1	41.2	56.1/43.9	26.4
1940	131,669,275		44.2	56.5/43.5	29.0
1950	150,697,361	14.5	50.7	64.0/36.0	30.2
1960	179,323,175	18.5	50.6	69.9/30.1	29.5
1970	203,302,031	13.4	57.4	73.5/26.5	28.0
1980	226,545,805	11.4	64.0	73.7/26.3	30.0
1990	248,709,873	9.8	NA	NA	33.0

NA = Not available

For how many of the census years from 1900 to 1980 was the ration of the urban population to the rural population greater than 7 to 4?

◯ One ◯ Two ◯ Three ◯ Four ◯ Five

% correct:
No-Calculator = 34
Calculator-Available = 43

36% in calculator-available group used the calculator

% correct:
Available, not used = 27
Available, used = 71

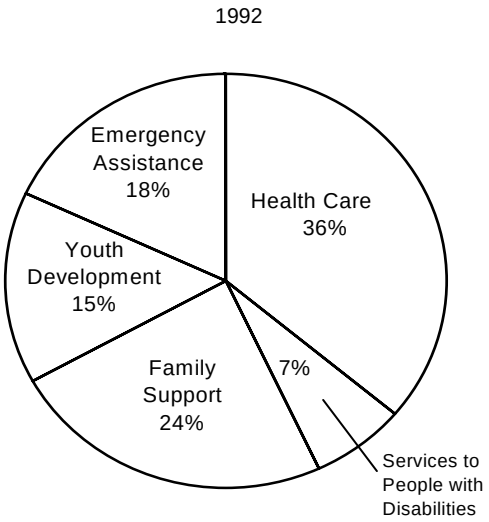
Mean GRE-Q Score:
Available, not used = 567
Available, used = 657

This difficult item became substantially easier with a calculator, but did not become trivial with calculator availability. Even with an available calculator, fewer than half of the examinees got this item correct.

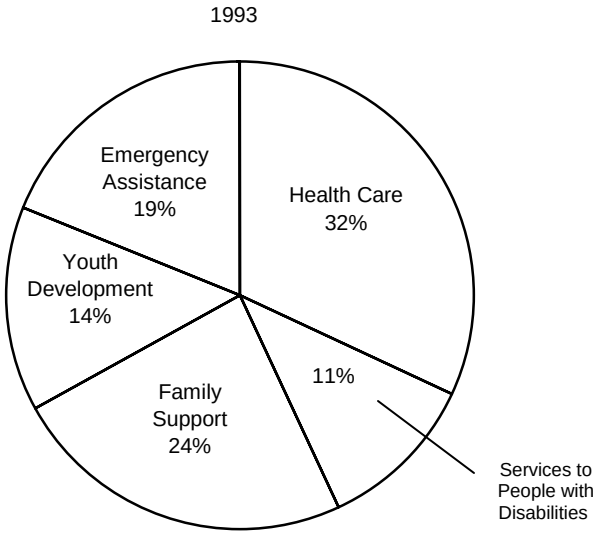
Item 5

These questions refer to the following graphs.

Distribution of Funds By Charity X



Total Funds Distributed: $2.54 million



Total Funds Distributed: $2.93 million

The increase in the amount of money distributed for family support from 1992 to 1993 was closest to which of the following?

- ⬭ $0
- ⬭ $24,000
- ⬭ $40,000
- ⬭ $60,000
- ⬭ $94,000

% correct:
No-calculator = 49
Calculator-available = 64

57% in calculator-available group used the calculator

% correct:
Available, not used = 43
Available, used = 81

Mean GRE-Q Score:
Available, not used = 578
Available, used = 619

This calculation-intensive item is of middle-difficulty and becomes considerably easier, but not trivially easy, with calculator availability.

Item 8

Pat purchased 4 large picture frames for $20.00 each, 100 medium-sized frames for $10.00 each, and 8 small frames for $5.00 each. What was the average price per picture frame?

- ⬭ $ 7.50
- ⬭ $10.00
- ⬭ $11.67
- ⬭ $15.00
- ⬭ $17.00

% correct:
No-calculator = 75
Calculator-available = 79

56% in calculator-available group used the calculator

% correct:	Mean GRE-Q Score:
available, not used = 72	available, not used = 600
available, used = 85	available, used = 597

This easy item becomes only slightly easier with calculator availability. Although it initially appears that a calculator might be useful, the calculations actually required are so simple that the calculator is of little use.

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